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DAB Subcommittee

In-band/On-channel (IBOC) Digital Audio Broadcasting (DAB) System Evaluation Guidelines

(as adopted by the Subcommittee on April 17, 1999 and revised on May 25, 1999)

Sponsored by the Consumer Electronics Manufacturers Association and the National Association of Broadcasters

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1 Introduction

The radio industry in the United States is on the brink of a revolution called Digital Audio Broadcasting (DAB). DAB promises to bring the missing piece to the analog-to-digital transition the radio industry's infrastructure is undergoing, turning radio into a *truly* digital medium poised for competition with other digital media.

A revolutionary change like this should not be undertaken lightly. Any technology developed for this purpose must be carefully, thoroughly, and objectively examined, considering both technological and economic aspects.

For a variety of reasons, in-band/on-channel (IBOC) DAB represents an attractive approach for broadcasters to introduce DAB in the United States. IBOC technology, now having been through several generations of development, appears to be reaching the point where it may be both feasible and ready for serious consideration. Design work continues by three independent IBOC system proponents and a regulatory process began in November 1998 when the FCC released for comment a Petition for Rulemaking on IBOC DAB, the first time ever this topic had been the subject of a formal proceeding.[1]

The NRSC's DAB Subcommittee—an industry-sponsored technical standards setting group composed of broadcasters, receiver manufacturers, and other allied concerns—has been working for the last year and a half with all interested IBOC technology developers to put in place a process which will allow it to assess this latest generation of IBOC and in particular, to determine if it can provide broadcasters and users with:

- A digital signal with significantly greater quality and durability than available from the AM and FM analog systems that presently exist in the United States;
- A digital service area that is at least equivalent to the host station's analog service area while simultaneously providing suitable protection in co-channel and adjacent channel situations;
- A smooth transition from analog to digital services.[2]

After considerable deliberation, the NRSC has decided that the first phase of its process will involve establishing the extent to which these individual IBOC systems meet these criteria. To that end, the Test Guidelines Working Group (TGWG) of the DAB Subcommittee drafted a series of test guideline documents outlining the recommended test procedures and technical

[1] See FCC RM-9395, "Amendment of Part 73 of the Commission's Rules to Permit the Introduction of Digital Audio Broadcasting in the AM and FM Broadcast Services."
[2] From "DAB Subcommittee Goals & Objectives," as adopted by the Subcommittee on May 14, 1998.

data that the NRSC needs to make such a determination, and describing the requirements a system submission must meet in order to be evaluated by the NRSC.[3]

The System Evaluation Guidelines document, a product of the NRSC's DAB Subcommittee Evaluation Working Group (EWG), Dr. H. Donald Messer, Chairman, is a companion to those test guidelines documents. Included herein is information on the process that the EWG intends to follow in the evaluation of technical data submitted to the NRSC by IBOC proponents. As with the test guidelines documents, this document is the result of a cooperative effort between broadcasters, receiver manufacturers, and IBOC system developers.

In the sections that follow, frequent reference is made to the test guidelines documents. Consequently, it is recommended that the test guidelines documents be reviewed thoroughly prior to consideration of this document. In some cases, the material contained herein expands upon that already presented in the test guidelines documents.

A number of other baseline assumptions, in addition to those presented in the test guidelines, underlie the evaluation guidelines which follow and are listed here along with a brief explanation. Some of these points will be further expanded upon in subsequent sections.

- System evaluation is self-contained – The DAB Subcommittee's objectives as given above focus on the comparison of an IBOC system's performance to that of existing analog radio services. It is not the intention of the NRSC to perform any "cross-system" comparisons at this time. Each system submitted will be evaluated on its intrinsic technical performance and its performance compared against existing analog services. A separate report will be prepared on each IBOC system submitted for evaluation.

  Since IBOC proponents are conducting their own test programs and are believed to be testing independently from one another, and since proponents are free to follow their own test procedures (those included in the test guidelines documents mentioned above are only recommendations), it would be difficult or impossible to perform meaningful cross-system comparisons. A test program designed to directly compare different IBOC systems would of necessity involve common test elements that are not present in the current NRSC process.

- Comparison with analog services – A major thrust of this evaluation process is the comparison of IBOC digital audio with existing AM and FM main channel audio. By and large, this comparison will utilize analog audio obtained by a proponent during its test program that, as is discussed in the test guidelines, will have been subjected to the same conditions as the digital portion of the signal.

[3] See "DAB Subcommittee – IBOC DAB System Test Guidelines – Part I – Laboratory Tests," adopted by the Subcommittee on 12/3/98, and "DAB Subcommittee – IBOC DAB System Test Guidelines – Part II – Field Tests," adopted by the Subcommittee on 3/4/99.

- Focus of evaluation is on "hybrid" performance – Many feel that the ultimate goal of IBOC DAB is to establish the "all digital" radio broadcasting infrastructure of the future and that the "hybrid" IBOC DAB systems being developed represent a transitional stage between the existing analog and future all-digital systems. A number of system proponents have indicated that their current system designs address both the hybrid and all-digital aspects of IBOC, and consequently the NRSC may receive data submissions including information on both hybrid and all-digital system implementations.

  In reality the transition from analog to digital radio broadcasting cannot be accomplished overnight. Even an IBOC system with an all-digital implementation included in its initial design is going to have to proceed through a lengthy transition phase during which the hybrid mode is going to be the principal mode of IBOC operation. Broadcasters, keenly aware of this, are especially concerned about how the hybrid IBOC signals are going to affect the existing analog signals which are the lifeblood of their businesses, particularly since the viability of a hybrid IBOC system meeting the DAB Subcommittee's objectives has never been proven.

  Furthermore, there is also a strong consensus within the broadcasting technical community that of the two IBOC DAB modes, hybrid and all-digital, implementation of the hybrid mode is at least if not more technically challenging than is the all-digital mode. Given all of these factors, the NRSC has found it appropriate to restrict the main focus of its current evaluation to hybrid IBOC DAB.

  The emphasis placed on hybrid systems should not be interpreted as a lack of interest in all-digital IBOC DAB systems – the NRSC encourages proponents to integrate an all-digital design into their plans. The broadcast industry will benefit most from a system that can transition seamlessly from hybrid to all-digital. Proponents are encouraged to include information on their system's hybrid to all-digital transition capabilities, and on all-digital system performance, as part of their submission to the NRSC and can expect the NRSC to review this information and comment on it in their final report.

  For the present time and effort, the most pressing need is to evaluate the hybrid mode of performance. To focus on the all-digital mode now without a complete understanding of the performance and tradeoffs associated with the hybrid mode of operation would be premature.

- Attention to the test guidelines is crucial – The closer a proponent's data submission comes to providing the information recommended in the test guidelines documents, the more likely it will be that the NRSC can achieve its evaluation objectives. A great deal of thought and untold years of experience in the technical aspects of broadcasting have gone into the preparation of the test guidelines documents. The NRSC believes that all of the requested data is important and necessary for a complete system evaluation. If a proponent's submission lacks requested information, then the NRSC may find it difficult to reach a conclusion regarding that system's suitability for deployment.

As is customary for NRSC projects, the dissemination of submitted IBOC system information will be coordinated by staff to interested DAB Subcommittee participants. The EWG

will serve as the focal point of the evaluation effort, under the direction of its Chairman, Dr. Messer, and the final evaluation report generated on a submission, when complete, will be released by this group to the DAB Subcommittee for formal adoption. Openness, fairness, and uniformity in evaluation of submissions will be at the forefront of the process, and will be incorporated into every aspect of system evaluation.

Another tenet of this process, and one that has been reinforced time and again by the IBOC proponents in their dialog within the NRSC, is that "time is of the essence." It is the NRSC's intention to begin processing any submission promptly upon receipt. Evaluation of a proponent's submittal will proceed in a manner that is consistent with the thorough and careful methods appropriate to a task of this importance. The NRSC's goal in this regard is not to delay but to accelerate the process of reaching important decisions about DAB deployment in the U.S.

2 Process overview

The system test guidelines documents contain a detailed explanation of the expected form and content of a proponent submission to the NRSC. This section of the System Evaluation Guidelines describes the NRSC's handling of a proponent's submission once received. Figure 1 of this guideline is a schematic representation of the NRSC evaluation process.

2.1 Pre-submission meetings

One of the NRSC's goals in conducting this evaluation program is that it proceed in an expedited fashion without sacrificing the quality of the evaluation. The primary purpose of the pre-submission meeting is to support this goal by ensuring that a proponent understands exactly what the test guidelines are requesting, and how their submission will be handled by the NRSC's evaluators, so that the form and content of a proponent's submission allows for as expedited a review as is possible.

Proponents are encouraged to contact the NRSC at any time during their testing process, especially if they have test guideline-related questions. Proponents must make contact 4 to 6 weeks prior to their planned submission date to arrange for (one or more) pre-submission meeting(s). Items to be covered at such a meeting include the following:

- Overview of proponent submission in particular, system description, test procedures followed, type of data being submitted (lab and/or field), data formatting, tests performed, identification of sub-contractors or consultants (*e.g.*, subjective evaluation facilities, consultants hired for independent verification of results), and identification of facilities used during tests (including broadcast facilities used for field testing).
- Update on NRSC evaluation process – In addition to the information contained in this evaluation guideline, there may be supplemental information on the evaluation process to convey.

During the pre-submission meeting(s), the proponent will meet with NAB and CEMA staff and their respective engineering consultants, and with the DAB Subcommittee and Evaluation Working Group Chairpersons. During the pre-submission review process, the following items in particular will be confirmed as being included in the proponent's submission:

a) Detailed system description, including a discussion of the tradeoffs and compromises made between various system aspects (especially tradeoffs affecting audio quality, interference performance, coverage, and compatibility with the analog host main channel audio).
b) Test procedure description, especially any deviations (including rationale) from the procedures recommended in the test guidelines documents.
c) Statement of oversight/review – as discussed in the test guidelines, proponents are expected to retain an independent, third-party observer who will follow and/or review the system testing (done by the proponent) closely, and personally certify the submitted results as an accurate record of the actual measured system performance.

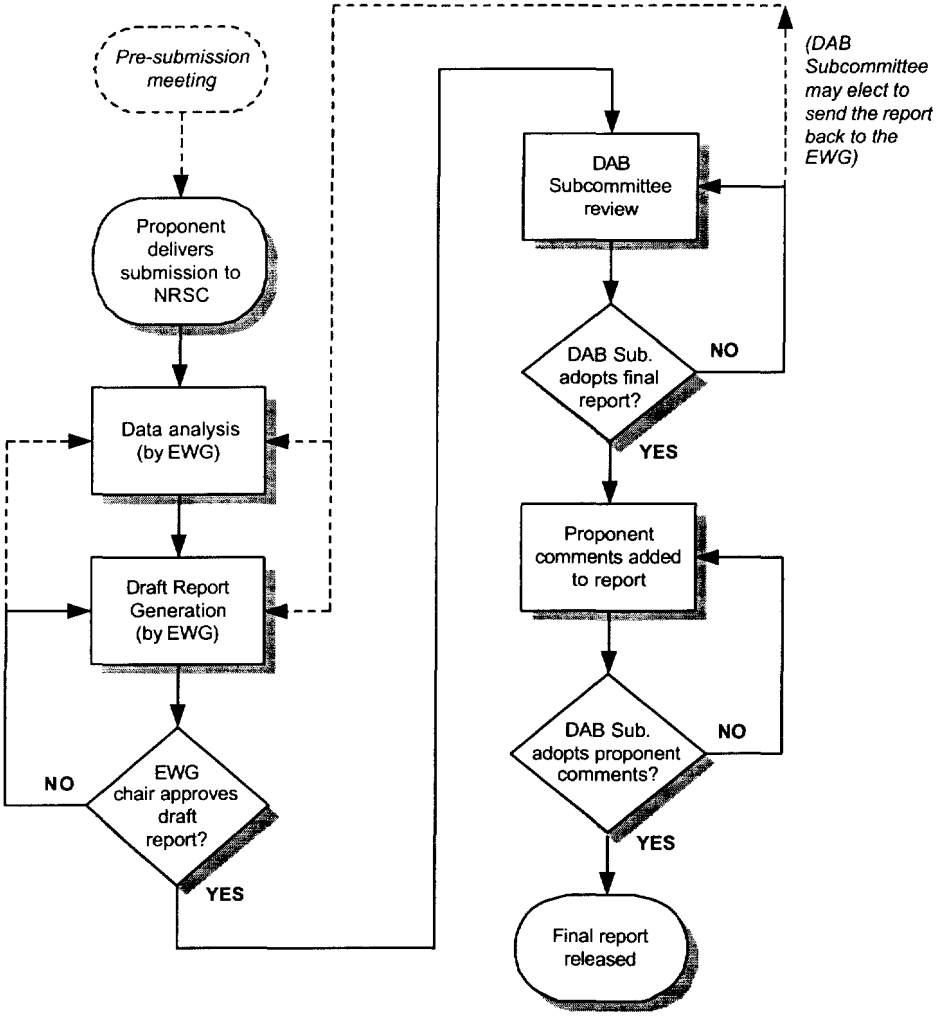

Figure 1. Schematic representation of the NRSC IBOC DAB system evaluation process

d) Complete system submission, including IBOC DAB for both the AM and FM bands, and if not, rationale behind the omission of one band. (Note – the NRSC may elect not to evaluate a submission that does not accommodate both AM and FM bands.)
e) Test results represent performance of completed system (not interim or preliminary results).
f) A sufficient quantity of test result data such that a meaningful evaluation can be performed. The test matrices portions of the test guidelines (Appendices D and E in Parts I and II) will be utilized in this determination.

An early dialog on these matters between a proponent and the NRSC should help expedite the evaluation process.

2.2 Data submission

Once the pre-submission meeting has occurred, the next step is for the proponent to deliver their submission to the NRSC. Two copies of all materials should be prepared, with one copy being delivered to CEMA and one to NAB. Proponents will be expected to sign a release form upon submittal acknowledging their understanding of the evaluation process as outlined in this guideline. It will be the NRSC's policy to refer any requests it receives for additional copies of the submission (not including those needed for official Committee business) to the proponent.

If desired, a proponent can accompany their submittal with an oral presentation to the DAB Subcommittee, for the purpose of presenting the technical details of their system, or to highlight key results, etc. Such a presentation must be coordinated with NAB and CEMA staff at least 4 weeks prior to the desired presentation date.

2.3 Data analysis

A thorough analysis of the submission will be conducted by the EWG. Additional information on the analysis portion of the process is given below in the section entitled "Data analysis." The proponent whose submission is being considered will be expected to respond to inquiries from the EWG which are likely to arise as the submission is evaluated.

2.4 Report generation

The end product of the NRSC's evaluation will be a final report drafted by the EWG and referred to the DAB Subcommittee for formal adoption. As mentioned earlier, this report will discuss only the submitted system and its comparison with existing analog services; no comparisons with other digital audio transmission systems, IBOC or otherwise, will be contained in the report. Additional information on the report generation portion of the process is given below in the section entitled "Report Generation." As with the data analysis phase of system evaluation, proponent participation in the report generation phase of the process will be limited.

2.5 DAB Subcommittee adoption

After the EWG Chair is satisfied that the EWG final report on a system evaluation is complete, it will be sent up to the DAB Subcommittee for consideration. There, it will be discussed and debated and either formally adopted or sent back to the EWG for additional work.

2.6 Proponent comments

Upon formal adoption by the DAB Subcommittee, the proponent whose system was evaluated will be given an opportunity to officially comment on the adopted report and have those comments incorporated into the report itself as an appendix. The purpose of these

comments would be to explain specific results and/or further clarify or expand upon the conclusions stated in the report, including dissention with or affirmation of those conclusions. These proponent comments are subject to DAB Subcommittee review and adoption.

2.7 Final report released

At the conclusion of this process, the evaluation report will be formally released to the public, including a formal submission jointly by CEMA and NAB to the FCC in any relevant IBOC DAB proceeding.

Note that EWG participants will be encouraged to withhold public statements regarding the evaluation of submissions until the process is complete, to minimize the possibility of pre-judgement or misunderstanding based on partial or incomplete information. The DAB Subcommittee chairman is the official spokesperson for all matters pertaining to the work of the EWG; all requests for information originating outside of the NRSC should be referred to that person.

3 Data Formatting

The format of a proponent submission, that is, the way in which the submitted information is organized and presented, will have a significant bearing on how rapidly and effectively the EWG can perform its evaluation. Proponents should bear this in mind as they prepare their material for submission and can expect that data formatting will be one of the topics discussed during their pre-session meeting(s) with the NRSC.

Since proponents are planning and executing their own test programs, the NRSC has no foreknowledge of the contents of proponent submissions, and consequently some of the data formatting suggestions being made in this document (as well as in the test guidelines) may not apply to a particular proponent submission. Proponents are free to assemble submissions as they see fit; ideally, a proponent submission will closely follow the organization of the pertinent test guidelines document. Proponents are asked to pay special attention to Appendices D and E (for both Part I and Part II) as they prepare their submissions and to organize the main body of the test data according to these test matrices.

Additional specific suggestions regarding submissions include the following:

- Recorded audio – the NRSC expects that proponents will use a variety of recording media for data collection including but not limited to digital audio tape (DAT) and digital recording directly onto hard disks and/or compact discs (CDs).

  The preferred format for audio recording submission to the NRSC is linear CD audio with a sampling rate of 44.1 kHz. Use of the CD format minimizes or eliminates the possibility of alteration of the submitted material and allows the evaluators to make use of widely available, high-quality playback equipment. Alternatively, a proponent may elect to submit audio in DAT format.

  The use of digital audio compression (for the purpose of bit rate reduction) at any point in the audio collection process would be inadvisable, and the NRSC assumes that the only digital audio compression existing in any submitted recordings is that of the IBOC perceptual audio coding system alone.

- Computer-based data – in the event that a proponent submits data in computer form, it should be in "machine-readable" format, using tabs, commas, or quotation marks to delimit the different fields of data. Spaces may also be used as a delimiter in combination with the delimiters identified above or, when on ambiguity would result, alone. Data may also be presented in any format that can be imported into a Microsoft Excel spreadsheet.

4 Data Analysis

The primary objective of the NRSC under its current IBOC evaluation effort is to establish whether or not an IBOC system outperforms existing analog technology, and if so, to what extent. The NRSC's ability to achieve this objective is enhanced if a proponent has followed the recommendations of the NRSC's test guidelines. Proponents are encouraged to actively participate in the NRSC process and to respond in a timely and forthcoming manner to EWG requests for additional information and clarification.

4.1 System compromises

It has become clear to the NRSC over time that a successful IBOC DAB technology is likely to involve a number of compromises and tradeoffs among key aspects of the system. For example, a proponent will have made decisions about the number of bits to allocate to source coding, and the number of bits to allocate to channel coding with this decision representing a tradeoff between audio quality and signal robustness. What is not clear at this point, and what a proponent's submission needs to establish, is exactly how and why the compromises for a given system were made, and the effect, if any, of these compromises on the analog and digital signals that will need to co-exist in the radio band.

Given this situation, and not knowing how a proponent is likely to deal with the numerous tradeoffs to be made, it is impossible for the NRSC to determine in advance exactly what set of tradeoffs result in an IBOC system with "significantly greater quality and durability" than existing analog systems. In the absence of measured system performance, such a determination would suffer from the following deficiencies:

- It would be arbitrary – for example, how would one decide how much additional coverage area for an IBOC signal represents significant improvement – 10%? 25%? Before such benchmarks can be set, one first needs to know the magnitude of improvement possible given the state of the art.

- There are so many factors to consider – if, for example, audio quality is improved significantly but digital coverage area is less extensive than is the case with existing analog technology, then could the overall performance be judged as significantly improved? Again, it would be impossible to reach such a conclusion without having first reviewed all of the performance data, to establish a benchmark.

- There are too many possible tradeoffs and compromises – if the NRSC were to try and quantify "significant improvement" before seeing any data, how could it decide among the myriad of tradeoffs and compromises possible? This would border on trying to design a proponent's system.

Only after a system's data has been evaluated and the technical performance pinned to a system's tradeoffs and compromises is known will it be possible to say if an IBOC system represents a significant improvement over analog services. Even then, such an assessment will

be challenging. Assessment of system tradeoffs is expected to be one of the EWG's more difficult tasks in evaluation.

4.2 Baseline analog performance

Given that it is not possible to quantify "significantly improved" performance prior to data analysis, the NRSC needs to quantify for proponents the baseline analog performance to which an IBOC system will be evaluated as this is much more tractable. Simply stated, baseline analog performance is the performance representative of today's analog services. Clearly, an IBOC system that is not at least as good as existing analog services would not be considered "significantly improved."

The following sub-sections discuss some of these key parameters. The task of the EWG will be to review each aspect of system performance for which data has been submitted and to determine whether or not the submitted IBOC system performance exceeds the corresponding baseline analog performance, and, if so, to what degree.

4.2.1 Audio quality (IBOC digital audio)

Characterization of the audio quality of a perceptually-coded system is hampered by the fact that key objective performance parameters such as signal-to-noise ratio and total harmonic distortion cannot be meaningfully applied to their analysis. Subjective evaluation against a signal with known properties is the best way currently available for evaluating the quality of perceptually coded audio.

Perhaps the best "historical" audio quality baselines for AM and FM radio are obtained from the NRSC's AMAX specification (for AM), and the (now retired) FCC rules for "proof of performance" (for FM), which stipulate minimum performance parameters for AM and FM shown in Table 1.

Table 1. Historical audio quality baseline performance for AM and FM analog radio (transmission plant specifications)

Parameter	AM	FM
Frequency response	Flat response (tolerance of +1.5/-3 dB) from 50 Hz to 7.5 kHz	Flat response (tolerance of ±1.5 dB) from 50 Hz to 15 kHz
THD	less than 2%	less than 1%
SNR	at least 50 dB	at least 60 dB
Stereo separation	N/A	at least 30 dB
(Source)	NRSC AMAX specification	Pre-1986 version of Section 73.1590 of the FCC Rules entitled "Equipment Performance Measurements"

These historical audio quality baselines are descriptions of the minimum performance expectations of the transmission systems, given perfect channel conditions and an ideal receiver. Many stations transmit signals that perform much better than these baseline values.

Because historical "proof of performance" baseline values do not represent what stations are capable of transmitting today, the NRSC feels that a comparison against audio obtained through reference chains (including receiver performance) is the fairest way to determine how the IBOC digital audio quality compares against existing services. As discussed in the laboratory system test guidelines, the NRSC recommends that proponents compare the digital audio quality of their systems against that obtained using the AM and FM NRSC reference chains. These reference chains are representative of the current state of the art of AM and FM radio. The NRSC reference chain performance parameters are given in Table 2.

4.2.2 Service area

Both AM and FM IBOC systems should provide a service area that, on a station-by-station basis, matches or exceeds the interference-limited service area of the host analog station. Station locations and, for FM stations only, antenna heights above average terrain for the IBOC facilities should be assumed to be the same as the host analog stations. IBOC systems should not require a change of the existing standards of allocation used in the domestic AM and FM broadcast services.

Table 2. NRSC reference chain audio quality baseline performance for AM and FM analog radio (total system performance including receiver)

Parameter	AM	FM
Frequency response	[ ]	[ ]
THD	[ ]	[ ]
SNR	[ ]	[ ]
Stereo separation	[ ]	[ ]

† *Values are currently being measured on the reference station equipment and will be included when available. Refer to the Laboratory Test Guidelines document for additional information on the NRSC reference chain.*

Actual interference-free service areas are variable, depending on individual receiver characteristics. From a regulatory standpoint, interference-free analog service areas for FM stations are determined at the outer limit of FCC protected analog service on the basis of a co-channel desired-to-undesired (D/U) signal strength ratio of 20 dB, a first adjacent channel D/U of 6 dB, and a second and third adjacent channel D/U of –40 dB. Desired or service signal strength is based on median f(50,50) field strength, and the undesired or interfering signal strength is based on median f(50,10) field strength. The f(x,y) notation represents the field strength exceeded at x percent of locations y percent of the time.

The actual range of viable coverage, in the absence of interference, exceeds statutory limits for most receivers. The statutory outer limit of analog service in the absence of interference for FM stations varies with the class of the channel on which the FM station operates. For Class B FM stations, the outer limit is 54 dBμV which corresponds to a median f(50,50) field strength of 0.5 millivolt per meter (mV/m). For Class B1 stations, the outer limit is 57 dBμV which corresponds to a median f(50,50) field strength of 0.7 mV/m. For all other classes of FM station, the outer limit is 60 dBμV which corresponds to a median f(50,50) field strength of 1.0 mV/m.

As with FM, the actual range of viable coverage for AM, in the absence of interference, exceeds statutory limits for most receivers. Daytime FCC protected interference-free analog service areas for AM stations are determined on the basis of a co-channel D/U of 26 dB at the desired 0.1 mV/m contour for Class A stations and the desired 0.5 mV/m contour for all other classes; a first adjacent channel D/U of 6 dB at the desired 0.5 mV/m contour; a second adjacent channel D/U of dB at the desired 5 mV/m contour; and a third adjacent channel D/U of 0 dB at the desired 25 mV/m contour.

IBOC proponents should recognize that many AM stations, and especially those in rural areas, provide reliable daytime service out to their respective 0.5 mV/m contours. The outer limit of daytime analog service in the absence of interference for AM stations is assumed to be the 2 mV/m contour.

The outer limit of nighttime analog groundwave service for AM stations is the calculated nighttime interference-free contour. The signal strength at the nighttime interference free contour varies from station to station. An IBOC DAB system that provides reliable service during the daytime within a given analog service area is likely to provide adequate service at night within the analog nighttime interference-free contour.

While some AM stations provide a secondary nighttime service by skywave, the propagation characteristics of the channel become extremely time variant at night and impairments to satisfactory reception such as interference and fading become controlling factors. The impact of these time-variant changes in an AM channel at night on the performance of an IBOC DAB system will be considered.

The EWG will also consider the performance of IBOC DAB systems in geographic areas in and proximate to the nulls in AM directional antenna horizontal plane patterns. Frequency dependent phase changes and asymmetric narrowing of the AM channel bandwidth in and around nulls on the proper operation of IBOC systems will be of particular interest.

4.2.3 Durability

The durability of a radio signal is characterized by its ability to withstand interference from other radio signals (co-channel, 1st adjacent channel, and 2nd adjacent channel signals in particular) and to withstand the impairing effects of the channel. In FM, multipath fading is the predominant form of channel impairment, while for AM, atmospheric noise and the attenuation due to grounded structures are major impairments.

4.2.4 Acquisition performance

Radio listeners have an expectation, gained from their experience with existing analog services, that a radio once tuned to an active frequency will acquire the signal rapidly, usually in less than 1 second. While the NRSC recognizes that it may be difficult for a digital audio system, in particular one incorporating advanced signal processing algorithms for robustness, to acquire rapidly, it must nevertheless utilize the "less than one second" baseline of performance in evaluating these systems, since this is the kind of performance that consumer acceptance of this service will demand.

4.2.5 Auxiliary data capacity

Many industry observers have suggested that one of the most important benefits to be realized in adopting a DAB system is the intrinsic auxiliary data capacity (i.e. data capacity not used for the main channel digital audio signal) likely to be available. For existing FM, the NRSC considers a continuously available information rate of approximately 10 kbps to be the baseline performance for auxiliary data capacity. This represents the average data carrying capacity of the digital subcarrier technologies tested by the NRSC's High-speed FM Subcarrier Subcommittee in the 1995-1997 time frame.

For AM, auxiliary data services are not currently supported and hence there is no reasonable baseline of performance established. Consequently, any auxiliary data capacity at all for AM will represent a significant improvement, however, the NRSC suggests that the minimum usable capacity would be equivalent to that offered by the NRSC RBDS standard (an FM digital subcarrier standard) which is an information rate of approximately 700 bits/sec.

4.2.6 Performance at the edge of coverage

Some digital broadcasting schemes, for example, the ATSC DTV system, and the Eureka-147 DAB system, exhibit a "cliff-effect" failure at the edge of their service area. That is, they exhibit excellent performance as long as the signal level into the receiver is above some threshold value, but once it goes below this value, they stop functioning completely.

As with acquisition performance discussed earlier, an IBOC DAB systems performance at the edge of coverage could also have important ramifications as far as consumer acceptance of the service is concerned. Listeners have come to expect that a signal will degrade gradually, since this is the nature of existing radio services. The EWG will be paying close attention to this aspect of system performance as it examines a submission.

4.3 Potential degradation to host analog signal

Another issue the EWG needs to address is what level of potential degradation of the *host analog* signal of an IBOC system is acceptable. This gets to the very heart of how potential tradeoffs and compromises are to be considered in this evaluation process.

It may be necessary to tolerate some amount of degradation (with respect to existing services) in the analog host since there is now a new, "significantly improved" digital service component of the broadcast signal. It is difficult for the NRSC to state, before having analyzed the data, the level of degradation that may be considered acceptable.

Some of the IBOC system proponents view "hybrid" IBOC systems as a transition to an all-digital approach, and have indicated that these all-digital approaches will be integrated into their IBOC systems from the start. In these cases, a rationale might exist to accept a different level of degradation in the analog host during the hybrid period than if there were no integrated transition path to all-digital.

4.4 Audio recordings

The Test Guidelines documents make numerous references to submission of audio recordings in addition to the requests for written material such as test procedures, test data, system information, etc. These recordings will form an integral part of the NRSC's evaluation and should be considered by proponents to be one of the more important items to be submitted.

Since a proponent's submission is expected to include numerous subjective evaluation results of audio performance, for example, establishing unimpaired digital audio quality of their system, along with the other requested data, the NRSC does not intend to conduct further evaluations of this sort using the audio recordings it receives. However, it would be impossible for the NRSC to conduct a credible, thorough evaluation of a digital audio broadcasting system without reviewing the audio recordings that correspond to the submitted data on that system.

One aspect of expected NRSC audio recording review can be characterized as a "reality check," giving evaluators an opportunity to hear and experience for themselves various aspects of a system's performance as indicated in the data report. Some examples of this include the following:

- TOA, POF assessment – in laboratory impairment tests, proponents are asked to establish the "threshold of audibility (TOA)" and "point of failure (POF)" of their systems under various conditions. Audio recordings corresponding to the TOA and POF behavior will be vital so that evaluators can know exactly the characteristics of TOA and POF as used in the data report.

- Impairment observations – the field test guidelines suggest that proponents conduct "impairment observations" in a mobile reception environment, and further that they record both the analog (host) and digital audio signals being simultaneously received. While a written report on these impairments is extremely useful, evaluators will also need to listen to the recorded audio so that they can fully understand the nature of the impaired performance, and can properly interpret the written record.

An equally important but perhaps less tangible role fulfilled by audio recording review is that it gives the evaluators an opportunity to establish a "feel" for how a system sounds under the various conditions it was subjected to during testing. Audio recordings made during a carefully conducted system test, under carefully monitored conditions, with additional supplementary information available (such as received signal strength or simultaneously recorded analog audio), will be of far greater value to system evaluators than would audio

collected under less exacting conditions, such as the "demonstrations" conducted by proponents for the NRSC (and others) in the past.

By and large, EWG members are broadcasting industry professionals with years of experience and have spent considerable time and effort forming opinions about broadcast audio based on listening to it. One of the suggested audio materials in the lab test guidelines— the so-called "long-form" audio—was included so that broadcasters and receiver manufacturers could hear some "real-world" material, making it possible for them to better gauge how an IBOC system compares to existing analog services from a listening standpoint. Submission of long-form audio recordings from the lab tests, and audio-of-opportunity recordings from the field tests, will give them an opportunity to do this.

5 Report generation

Once data analysis is complete, and supplementary information included in a submission has been considered, the EWG will prepare a report summarizing its findings, including its determination of whether the IBOC system evaluated represents a significant improvement over existing services, if this determination can be made. Discussed in this section (and in Appendix A) of the Evaluation Guidelines document are some of the qualitative factors and performance goals which will be considered as the EWG attempts to make this determination, as well as some particular aspects of the report document itself.

5.1 Qualitative factors and performance goals

Upon reaching the report generation phase of the evaluation process, the EWG will have before it information on a system's design, laboratory and field test data (including audio recordings), and the results of the analysis performed on this data. The EWG, as it prepares its report, will review all of this information and reach a final conclusion as to whether a system represents a significant improvement over existing analog services. Discussed in Appendix A are some of the qualitative factors and performance goals the EWG will be considering as it conducts this review.

5.2 Report structure

Each IBOC system submitted for evaluation to the NRSC will be reported on individually. The EWG will strive to follow a common format, if it should have the opportunity to generate more than one report (due to the evaluation of more than one system), however, reports on different systems may be different due to differences existing in the various submissions.

Items to be included in the system evaluation report include the following:

- Results of data analysis – item by item and overall
- Conclusions – does the system represent a significant improvement over existing services?
  → If yes, an explanation of exactly how this is so
  → If no, then the reasons why not
- Dissenting opinions (if any) from participants (not proponents)

When the report is complete (as determined by the EWG Chair), it will be sent up to the DAB Subcommittee for consideration. There, it will be discussed and debated and either formally adopted or sent back to the EWG for additional work.

Upon formal adoption by the DAB Subcommittee, the proponent whose system was evaluated will be given an opportunity to officially comment on the adopted report and have those comments incorporated into the report itself as an appendix. The purpose of these comments would be to explain specific results and/or further clarify or expand upon the conclusions stated in the report, including dissention with those conclusions. These proponent comments are subject to DAB Subcommittee review and adoption.

Appendix A – Qualitative Factors and Performance Goals

The overall performance goal is the improvement in fidelity and robustness of the transmission system. Proponents and evaluators should consider the overall transmission and listening experience weighed against the cost and complexity of the system when evaluating any of the specific performance goals listed in these guidelines. The success and acceptability of an IBOC system will be determined by how it meets the overall needs of the broadcaster, receiver manufacturer and the listener, as well as how it meets the performance goals specified in this document.

A.1 Qualitative Factors

A.1.1 Evaluation Categories

The EWG assumes that the comparison between a digital technology and its analog counterpart is based on the use of identical antenna locations and heights. Any change of existing standards of allocation necessary for a submitted IBOC system would bear upon this comparison and must be fully disclosed and explained by the proponent.

Described below are some of the current strengths and weaknesses of the analog AM and FM broadcasting services against which IBOC systems will be compared. Before discussing these characteristics of AM and FM broadcasting, three primary categories of evaluation are identified: fidelity, durability and flexibility.

A.1.1.1 Fidelity

"Fidelity" represents how well the input to the transmitter *can be* replicated at the output of a receiver. Consumer acceptance of an IBOC technology may be enhanced if the technology improves on the fidelity of analog AM and FM.

It is important to note that fidelity is defined in terms of what *can be* delivered to the listener. A number of variables will affect the audio a listener actually hears. Good fidelity, then, is a description of the upper bound of audio performance of a broadcast medium assuming ideal source material is sent under ideal transmission, propagation, reception and listening conditions. The subjective listening tests recommended in the test guidelines will provide information about how overall fidelity of a new digital technology compares with current analog technology.

A.1.1.2 Durability

Durability refers to the ability of the received program content to resist interruption and the ability of the received programs fidelity to resist being compromised by interference and channel impairments.

- Interference:

- Caused by co- or adjacent channel signals

- Impairments:
  - Environmental noise (man-made or atmospheric)
  - Shielding (structural or terrain shadowing)
  - Grounded conductive structures (e.g. obstructions that introduce amplitude and phase changes to the channel)
  - Multipath
  - Receiver motion
  - Receiver overload induced intermodulation products (*e.g.*, blanketing)
  - Directional antenna pattern signal distortions

IBOC system evaluations will include an assessment of whether the coverage area and durability of an IBOC signal at least matches its analog host's coverage area and durability. The listening experience at both the central listening area and the edge of coverage must be examined. This examination will, at a minimum, look at the Threshold of Audibility (TOA) and Point of Failure (POF) throughout the coverage area.

Most stations in the United States are limited in coverage by co- and adjacent channel interference. This interference directly influences the coverage area of the analog and potentially the digital signals. Within the coverage area, durability will be affected by impairments which may so degrade the signal that listeners tune out.

An IBOC system's ability to survive both interference and impairments will directly affect public perception of this technology.

A.1.1.3 Flexibility

A technology's flexibility has both technical and economic components. The term flexibility is used here to represent the potential of a technology to be adapted by broadcasters and manufacturers to meet the needs of listeners and consumers. Currently, analog receiver manufacturers make a range of products tailored to the price and performance needs of different kinds of radio users. Automobile radios are optimized to provide the best mobile reception possible, while the ten dollar pocket radio sacrifices performance to maximize affordability. For IBOC systems, codec technologies, communications protocols, and receiver chipset requirements can influence the flexibility of the system designs.

Some of the different aspects of a technology's flexibility to consider include:

- Capability to support a diversity of receiver types with a diversity of features and cost;

- Capability to improve the technology and meet consumer expectations by the addition of backward-compatible enhancements;

- Capability to provide features and services to improve station-listener relationship;

- Capability to be forward compatible to allow migration to an all-digital mode.

A.2 Qualitative performance goals

A.2.1 Fidelity of transmission systems

A.2.1.1 Frequency response and distortion

Unlike with analog systems, there will be less opportunity to influence a digital transmission system once it is installed, therefore the best fidelity a digital system can offer will be highly dependent on the fundamentals of its design.

Performance goal: *For FM IBOC systems, the frequency response and distortion fidelity of a digital technology should be comparable to or better than the best FM transmission facilities in the country. AM IBOC systems should deliver a fidelity that approaches present FM analog fidelity.*

This next performance goal applies to FM-band IBOC and to a lesser degree, to AM-band IBOC as well.

Performance goal: *To alleviate the effects of channel impairments and interference, it may be acceptable to diminish distortion and frequency response fidelity to maintain audio free of dropouts and noticeable artifacts.*

A.2.1.2 Noise

An FM transmission system that meets the former FCC noise specifications (refer to Table 1, Section 4.2) has a noise fidelity that meets consumer requirements under optimum listening conditions. Again, AM transmission systems performance is not as good as FM in this regard. However, much source material now has better noise characteristics than the transmission system can deliver.

Broadcasters use audio processing to be more consistently audible under the variety of reception and listening conditions in the marketplace. This tends to maximize the instantaneous audio to noise ratio. Noise fidelity of FM under ideal reception conditions is therefore an acceptable level of performance. Noise fidelity of a new technology should strive to be equivalent to the performance of typical source material, such as CDs.

Performance goal: *To alleviate the effect of impairments and interference it may be acceptable to compromise noise fidelity to maintain audio free of dropouts and noticeable artifacts.*

A.2.1.3 Stereo separation

Good stereo separation is an important goal for any IBOC system but it should be recognized that its importance to the overall fidelity of a system may be masked by the limitations of the typical listening environment. It is generally accepted that stereo separation

of 35 dB is sufficient for the enjoyment of stereo in the ideal listening environment. This should remain a goal of new technologies. Certain receivers, listening environments, and listeners do not presently obtain this performance.

As a receiver is moved beyond the range of a full-quieting signal level, the stereo component begins to develop noise. Automobile radio manufacturers have ably adapted FM receiver design to manipulate the high frequency content and stereo separation to extend the tolerable range of mobile reception.

Performance goal: *In the digital domain, stereo separation is a characteristic of fidelity that may be acceptable to compromise in response to channel impairments.*

A.2.1.4 Fidelity characteristics of digital technologies

In the analog domain, fidelity may be affected by distortions in frequency (and phase) response, nonlinearities producing other various forms of distortion (for example, intermodulation distortion), and simple noise level. In some existing radio stations, the audio processing of the analog signal which is not included in this evaluation, if not judiciously applied, may tend to produce the more dynamic artifacts such as pumping, noise modulation, or dynamic spectral and stereo platform shifts. In the digital domain, source coding technologies inherently manipulate dynamic, spectral, and psychoacoustic components of the audio.

Performance goal: *Source coding manipulations of the audio should not cause artifacts that noticeably reduce the fidelity of the system throughout the service area.*

Due to their numerical nature, digital representations of audio signals have rigid upper limits in instantaneous level and do not begin to go into compression and distortion prior to clipping as would an analog representation. Thus, the headroom requirement for a digital system must be either more broad or more strict. A broader headroom requirement lowers the average program level closer to the noise floor. A stricter requirement would maintain less headroom by demanding that audio be more rigidly limited. Digital broadcasting is expected to engender new processor designs that will permit strict rather than broad headroom practices.

These differences in how headroom is handled remain an important factor to consider when comparing the dynamic range and noise characteristics of a digital technology with its analog counterpart. In digital systems, traditional noise measurement is not as meaningful as in analog. Expert listening will be required to evaluate noise effects in the digital and analog domains. Regarding dynamic range, it is important that the IBOC systems' perceptual audio coding algorithm can manage audio that is highly processed as well as audio that is not compressed in dynamic range.

Performance goal: *There should be sufficient apparent dynamic range to enable low level and dynamic content to reproduce with the same fidelity as aggressively processed audio.*

A.2.2 Durability of transmission systems

One aspect of analog systems is that as fidelity is compromised by channel impairments, listeners may choose to tolerate it because the still-audible program content is compelling or the impairment is expected to be transitory. In this regard, FM is a durable medium. Nonetheless, there is clearly a demand for more durable service.

A.2.2.1 Interference

A viable IBOC system should operate successfully within present AM and FM service areas. Thus, IBOC systems should be sufficiently robust to survive co- and adjacent channel interference in a service area at least as great as existing analog stations.

Performance goal: *Digital systems should reach a service area that, on a station-by-station basis, matches or exceeds the actual interference-limited service area of the analog hosts.*

A.2.2.2 Impairments

Analog FM is susceptible to a range of impairments including:

- Deep ("stoplight") fades
- The distortion produced by multipath in mobile, fixed and portable situations
- Signal "flutter" produced by aircraft
- Reception that changes when people move in the vicinity of the radio
- Attenuation by buildings, and internal environmental noise
- Receiver overload induced intermodulation (in and out of official blanketing areas)

On the other hand, FM is relatively well protected from environmental noise.

The Analog AM broadcast service is susceptible to the following:

- Man-made and atmospheric noise
- Below ground-plane shielding (bridge effects, power lines and overhead signs)
- Receiver intermodulation
- Directional antenna pattern bandwidth distortions (phase and amplitude)

Digital technologies offer the opportunity to use advanced signal processing techniques, such as time diversity, to cover transient impairments. Fades and impairments that last too long or are too frequent will result in loss of audibility and ultimately failure.

Performance goal: *Digital technology will be considered to be better than analog against impairments if digital multipath and fade artifacts have the following characteristics:*

- *They are demonstrably less objectionable, less frequent in time and less prevalent in location than those of analog services;*
- *They maintain higher fidelity than analog for a preponderance of occurrences;*
- *They result in fewer total losses of intelligible audio than analog, and recovery from total loss is not significantly longer than analog in similar circumstances.*

A.2.3 Flexibility of transmission systems

FM broadcasting is a good example of a flexible broadcasting system that was able to benefit from enhancements over the decades. The addition of stereo audio to what was originally a monaural service is an example of one such enhancement. RBDS offers a very narrow data channel to transmit program-related information to listeners. Subcarrier technologies, including RBDS, permit broadcasters to use spectrum more efficiently to deliver services to niche segments of the population that otherwise could not take advantage of broadcast spectrum. FM receivers are designed for a range of user preferences and pocketbooks. Innovations in circuit component and design have permitted technological improvements in the fidelity, durability and flexibility of FM broadcasting. Transmitters are user-serviceable and continually becoming more reliable.

Performance goal: *A successful digital technology will:*

- *Reasonably protect the performance and flexibility of its analog host and adjacent channel stations;*
- *Provide a platform that can be improved in software, firmware and hardware in a manner that is compatible with its original technology;*
- *Give broadcasters tools to create features to enhance the listener experience and permit the medium to remain relevant and competitive in the coming decades.*

Appendix B – DAB Subcommittee Goals & Objectives